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A PILOT DATA ANALYSIS OF SEA SURFACE TEMPERATURES AND WIND SPEEDS MEASURED ON OCEANIC WEATHER SHIP PAPA - A SUMMARY

by

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A Pilot Data Analysis of Sea Surface Temperatures and Wind Speeds Measured on Oceanic Weather Ship PAPA - A Summary

by

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1. Introduction

This note describes the results of an exploratory data-analytic study of sea surface temperatures and wind speeds measured on Oceanic Weather Ship PAPA. The data consist of 15 years (1955-1969) of measurements taken every three hours. Two of the measurements recorded were of wind speed and sea surface temperature. Other measurements taken include air temperature and wind direction.

In Section 2 the results of a spectral analysis of the 15 years of sea surface temperatures are described. It indicates that sea surface temperatures exhibit noticeable 1 year, 6 month, 24 hour, and 12 hour cyclic components. The 24 hour and 12 hour components are modulated by yearly and seasonal effects.

In Section 3 the results of an analysis of average daily sea surface temperatures and average daily wind speeds during the Spring and Summer for three years 1964-66 are reported. After the two series were detrended, it was found that positive changes between days t and $t-1$ in the inverse residual sea surface temperature are associated with large residual wind speeds on day t and large residual sea surface temperatures on day $t-1$. This association can be explained by the behavior of the oceanic mixed layer depth.

1. Sea Surface Temperatures

In this section we describe a spectral analysis of sea surface temperatures taken on Ship PAPA. The data consist of 15 years (1955-1969) of measurements taken every three hours. The 5 leap days were removed leaving a data set of length 43,800 readings.

Figure 1 shows the data set. The most apparent feature of sea surface temperatures is the strong yearly cycle. Another feature is the change in the measurement reporting procedure which occurs 8 years into the record. The first 8 years of data appear to be more discrete than the last 7 years. Prior to 1963 the data were recorded with a 1° Fahrenheit resolution and then converted to degrees Celsius. Starting in 1963 the data were recorded with a 0.1° C resolution. The data record also appears to contain erroneous measurements and interpolations.

The ℓn (normalized periodogram) of the entire record of sea surface temperatures appears in Figures 2-5; (cf. Cox and Lewis [1966] p. 99). Figure 2 shows the entire ℓn periodogram; the horizontal line is at the ℓn 95% quantile of the maximum of 21,900 independent unit exponentials. Figure 3 shows the first hundred values of the ℓn (periodogram). The two peaks occur at $p = 15$ and 30 which correspond to cycles of 1 year and 6 months respectively. Figure 4 shows the values of the ℓn (periodogram) for p-values around the peak at $p = 5475$ which is the 24 hour cycle. Notice the local peaks at $p = 5490$ and 5460 which are 1 year side lobes. A second pair of side lobes occur at $p = 5408$ and 5542 which correspond to 81.7 day side lobes or seasonal side lobes. Figure 5 gives the ℓn (periodogram) for values of p around the peak at 10950, the 12 hour cycle. Again there are side lobes at $p = 10945, 10965$ (1 year) and $p = 10882, 11018$ (80.5 days or seasonal).

The side lobes indicate that sea surface temperatures are modulated by yearly and seasonal effects. It suggests that the sea surface temperatures in the same season in different years are statistically different; (cf. Bloomfield [1976] pp. 99-100).

R. W. Garwood has provided the following explanation for the year to year variability. The variability in sea surface temperatures in the same season of different years is due to the variability of the mixed layer depth in the ocean. The mixed layer depth is a function of surface heating of the ocean and ocean mixing by turbulence due to storms. The times between passage of, and the strength of, the storms varies from year to year. The surface heating is a function of the season of the year.

In summary, the ℓn (periodogram) of 15 years of sea surface temperatures indicate that the record has noticeable 1 year, 6 month, 24 hour, and 12 hour cyclic components. The 24 hour and 12 hour cycle components are modulated by year and seasonal effects.

2. Associations between average daily Sea Surface Temperatures and Average Daily Wind Speed

In this Section we will report on a pilot study of associations between average daily sea surface temperature and average daily wind speeds during the Spring and Summer (Julian days 91-272) for the years 1964 (year 10), 1965 (year 11), and 1966 (year 12).

P. A. W. Lewis and his associates have done a spectral analysis of 15 years (1955-1969) of Ship P wind speed data which was measured every three hours (Lewis[1983]). The analysis suggests that the wind speed data has cyclic components of 1 year, 6 month, 12 hours and 6 hours.

Associations between the average daily sea surface temperatures and average daily wind speeds may be confounded by the non-stationarity of the two series. Thus, the two series were detrended. In order to detrend the series in the same manner, the average daily sea surface temperatures and average daily wind speeds for Julian days 91-272 for each of years 10-12 were put into two-way tables having 26 rows (weeks) and 7 columns (days). The two-way tables were median polished (cf. McNeil [1977]) to obtain expressions of the form Data = typical value + day effect + week effect + residual. The residuals from the median polish were taken as the detrended series. Since both average daily sea surface temperatures and average daily wind speeds were treated in the same manner by this procedure, the residual series are comparable. Figure 6 (respectively 7) shows a plot of the median polish residuals of average daily sea surface temperatures (respectively wind speeds) for year 12. The plots for the other years are similar. The plots exhibit no apparent nonstationarity and show the typical pattern of many small values due to the use of median polish. The periodogram (not shown) of the residual sea surface temperature for year 12 shows a significant peak at 7 days which may be due to the fact that the median polish was done on a two-way table with rows of length 7 days. The periodograms of residual sea surface temperatures for the other two years do not show this effect.

The first 50 serial correlations were computed for each residual series. There is some correlation in the residual series particularly in the residual average sea surface temperatures in year 12. There appears to be a pattern in the correlations again suggesting possible nonstationarity introduced by the median polish. However, the correlation was judged not to be substantial enough to affect the results of this exploratory study.

Let $W(t)$ (respectively $S(t)$) denote the residual from median polish of the average daily wind speed (respectively sea surface temperature) on day t. Put

$$H(t) = \frac{1}{S(t)+1}, \qquad t = 91,\ldots,272.$$

where the constant 1 in the denominator was arbitrarily chosen to ensure that $H(t)$ is finite. The surface mixed layer depth of the ocean during the Spring and Summer is related to the inverse of sea surface temperature; (Garwood [1983]). Thus, $H(t)$ should be related to mixed layer depth.

Let

$$D(t) = H(t) - H(t-1) , \quad t = 92,\ldots,272$$

and

$$X(t) = \ell n(S(t) + 1) \quad t = 91,\ldots,272.$$

$D(t)$ is related to changes in mixed layer depth. We will concentrate on associations between $D(t)$ and $W(t)$ and $X(t-1)$.

For each year the quantiles of residual sea surface temperature $\{S(t) ; t = 91,\ldots,271\}$ were used to categorize $\{(D(t), W(t)), t = 92,\ldots,272\}$ in the following manner. Category I contains those $(D(t), W(t))$ such that $S(t-1)$ is less than or equal to the lower quartile of $\{S(t); t=91,\ldots,272\}$; Category II contains those data such that $S(t-1)$ is greater than the lower quartile but less than or equal to the median; Category III contains those data such that $S(t-1)$ is greater than the median but less than the upper quartile; and Category IV contains the remainder of the data. In brief, Category I is "very low"; Category II is "low"; Category III is "high"; and Category IV is "very high" as ordered by sea surface temperature on the previous day.

Figures 8-10 show plots of residual wind speed $W(t)$ versus $D(t)$ by residual sea surface temperature category for each of the three years. For each year the plot in the upper (lower) left hand corner corresponds to Category I (Category III); the plot in the upper (lower) right hand corner corresponds to Category II (Category IV).

All of the plots suggest that larger residual wind speeds are associated with larger values in the differences D(t). Further the association looks roughly linear. There is no strong indication that the association changes for different sea surface temperature categories.

For each year the quartiles of $\{W(t);\ t = 91,...,272\}$ were used to categorize $\{(D(t), X(t-1)),\ t = 92,...272\}$ in the same manner. The categorical plots of $X(t-1)$ versus $D(t)$ are shown in Figures 11-13, the arrangement of the plots by category is the same as for Figures 8-10. Once again the plots indicate that larger values of $D(t)$ are associated with larger values of $X(t-1)$. The association appears roughly linear. Again there is no strong indication that the association is different in different categories.

Regressions of the form

$$D(t) = a + b\,W(t) + cX(t-1) \qquad t = 92,...,272$$

were fit to the data in each of the three years using two procedures. One is least-squares, a classical procedure which is sensitive to possible outlying values in the data; (cf. Mosteller and Tukey [1977]). The second is a biweight procedure (cf. Mosteller and Tukey [1977] pp. 205) which is less sensitive to outlying values. The estimated coefficients can be found in Table 1. Plots of the residuals from the regression versus predicted $D(t)$ showed little structure. This suggests that the regression has removed most that is systematic or explainable in the data.

Regressions containing an interaction term of the form

$$D(t) = a + b\,W(t) + cX(t-1) + d(X(t-1) \times W(t))$$

were also fit. The estimated values appear in Table 2.

Table 1

Estimated Values for the Coefficients of

$$D(t) = a + b\, w(t) + cX(t-1)$$

Year	Least Squares Estimates (Std. Error) a	b	c	Biweight Estimates a	b	c
10	0.0141 (.017)	0.2027 (.048)	0.6510 (.090)	-0.0081	0.1267	0.6510
11	0.0144 (0.027)	0.1325 (0.074)	0.8969 (0.108)	-0.0214	0.1319	0.6120
12	0.0125 (0.024)	0.1475 (0.063)	0.7368 (0.092)	-0.0179	0.1368	0.4254

Table 2

Estimated Values for the Coefficients of

$$D(t) = a + b\, w(t) + cX(t-1) + d(X(t-1) \times w(t))$$

Year	Least Squares Estimates (Std. Error) a	b	c	d	Biweight Estimates a	b	c	d
10	0.0188 (0.017)	0.2175 (0.048)	0.6298 (0.090)	-0.6047 (0.311)	0.0104	0.1144	0.5202	0.26
11	0.0153 (0.027)	0.1504 (0.075)	0.8328 (0.115)	0.4474 (0.272)	-0.0210	0.1346	0.6114	-0.09
12	0.0314 (0.024)	0.1933 (0.062)	0.7193 (0.089)	-0.9222 (0.236)	-0.0202	0.1312	0.4023	0.20

The regressions indicate that larger differences in the inverse residual sea surface temperature, $D(t)$, are associated with larger residual wind speeds, $W(t)$ and larger ℓn (residual sea surface temperature) the day before, $S(t-1)$. There appears to be no significant interaction term of the form $W(t) \times X(t-1)$. The standard errors for the least squares estimates should be viewed with caution because of the correlation in the series $\{S(t)\}$ and $\{W(t)\}$. There is no suggestion that the association is different in the different years.

An explanation for the relationship suggested by R. W. Garwood is as follows. The mixed layer depth of the ocean during the Spring and Summer is related to the inverse of sea surface temperature. Thus $D(t)$ should be related to the change in mixed layer depth of the ocean between days t and $t-1$. Further $X(t-1) = \ell n(1 + S(t-1))$ is related to the mixed layer depth on day $t-1$. Thus the above association suggests that deepening (shallowing) of the ocean mixed layer depth during the Spring and Summer (Julian days 92-272) is associated with larger (smaller) wind speeds and shallower (deeper) mixed layer depths the day before.

During the Spring and Summer the mixed layer depth of the ocean is a function of solar warming and turbulant mixing attributable to storms. During periods of light (strong) winds the mixed layer becomes shallower (deeper). However, the effect of a storm on the mixed layer depth depends on "how deep the mixed layer is already". A storm of the same strength will cause a larger drop in sea surface temperature if the surface mixed layer is shallow than if it is deep.

The association found here agrees with a simpler related association found by Elsberry and Raney (1978) also using Ship P data. They defined sustained periods of above or below normal wind forcing as events and calculated the surface temperature change for each event. They found an association between an increase (decrease) in sea surface temperature and below (above) average wind speeds.

3. Conclusions

(1) Spectral Analyses of 15 year records of sea surface temperatures and wind speeds from Ship P showed strong yearly, seasonal and time of day effects.

The Spring-Summer periods of three years 1964-1966 were chosen for further study.

(2) After average daily sea surface temperatures and wind speeds for the period were detrended and the residuals examined, it was found that large changes between days t and $t-1$ in the inverse residual sea surface temperature are associated with large wind speeds on day t and large sea surface temperatures on day $t-1$. The association can be explained by the behavior of the oceanic mixed layer depth.

4. Acknowledgments

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References

P. Bloomfield. Fourier Analysis of Time Series: An Introduction. John Wiley and Sons, Inc. 1976.

D. R. Cox and P. A. W. Lewis. The Statistical Analysis of Series Events. Methuen and Co. 1966.

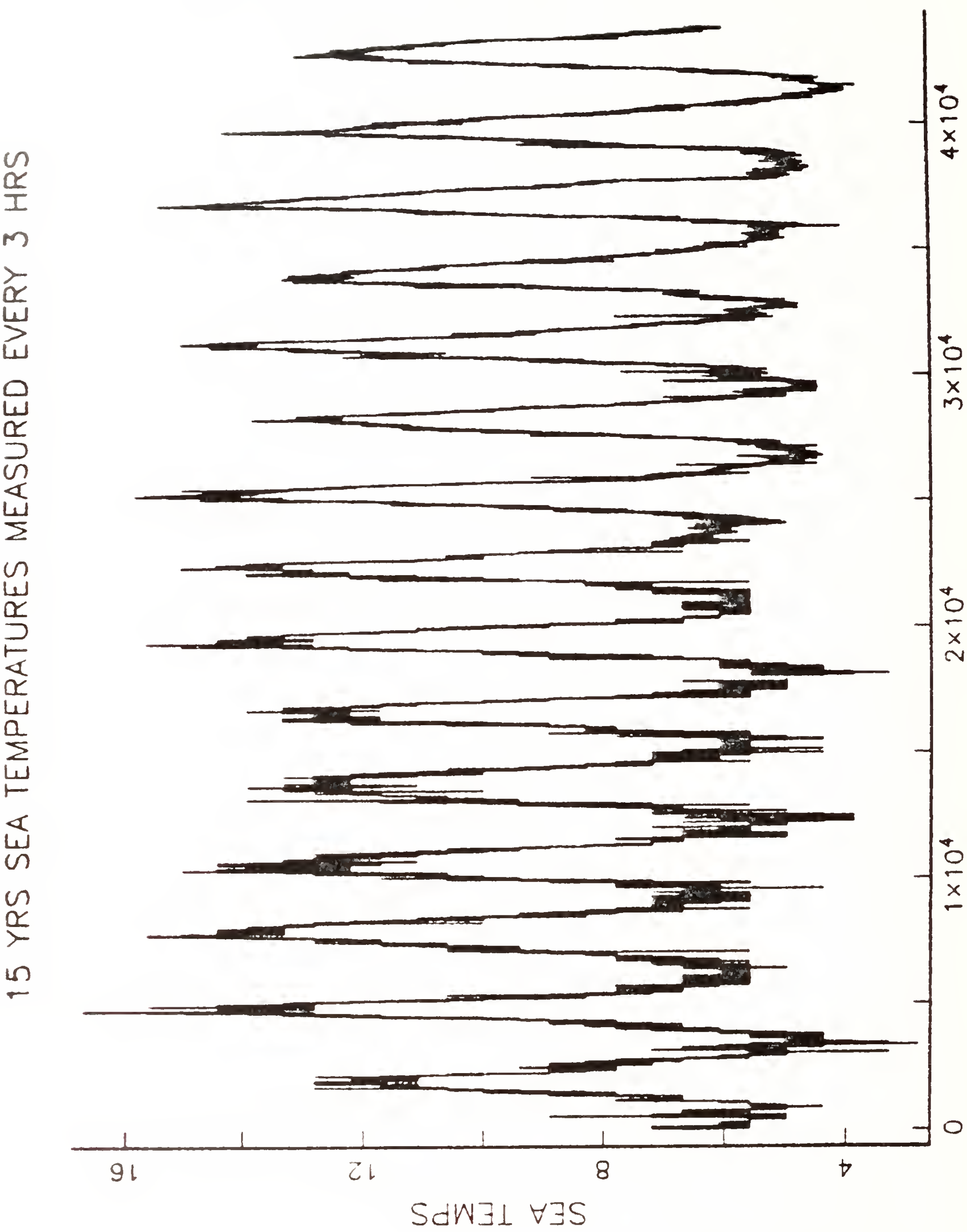
R. L. Elsberry and S. D. Raney. Sea Surface temperature response to variations in atmospheric wind forcing. J. Phys. Oceanogr. 8 (1978) 881-887.

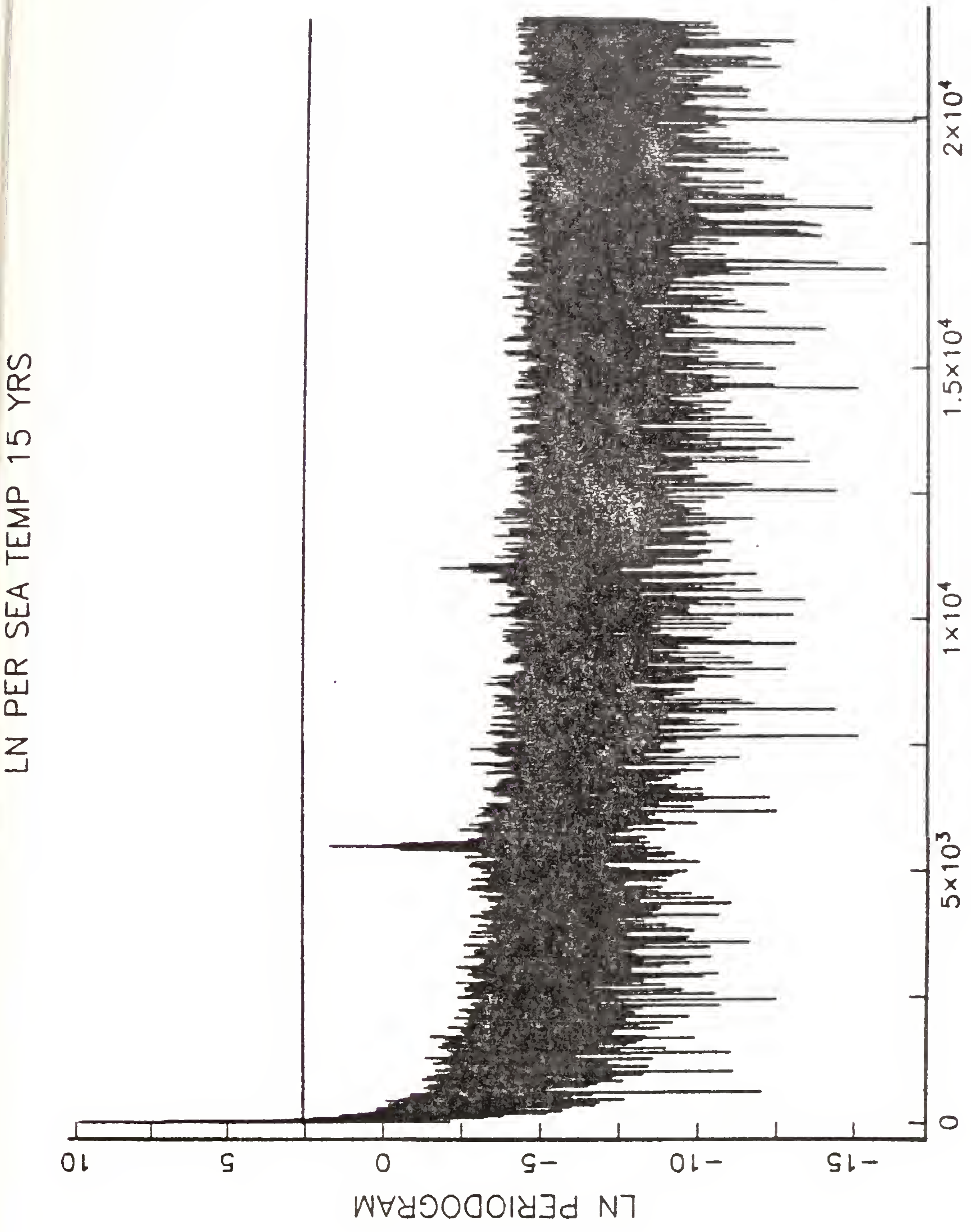
R. W. Garwood. Personal Communication, 1983.

P. A. W. Lewis. Personal Communication, 1983.

D. R. McNeil. Interactive Data Analysis. John Wiley and Sons, 1977.

F. Mosteller and J. W. Tukey. Data Analysis and Regression. Addison-Wesley, 1977.


15 YRS SEA TEMPERATURES MEASURED EVERY 3 HRS
SEA TEMPS
16
12
8
4
0
1×10⁴
2×10⁴
3×10⁴
4×10⁴



LN PER SEA TEMP 15 YRS
LN PERIODOGRAM
10
5
0
−5
−10
−15
0
5×10³
1×10⁴
1.5×10⁴
2×10⁴

Figure 2

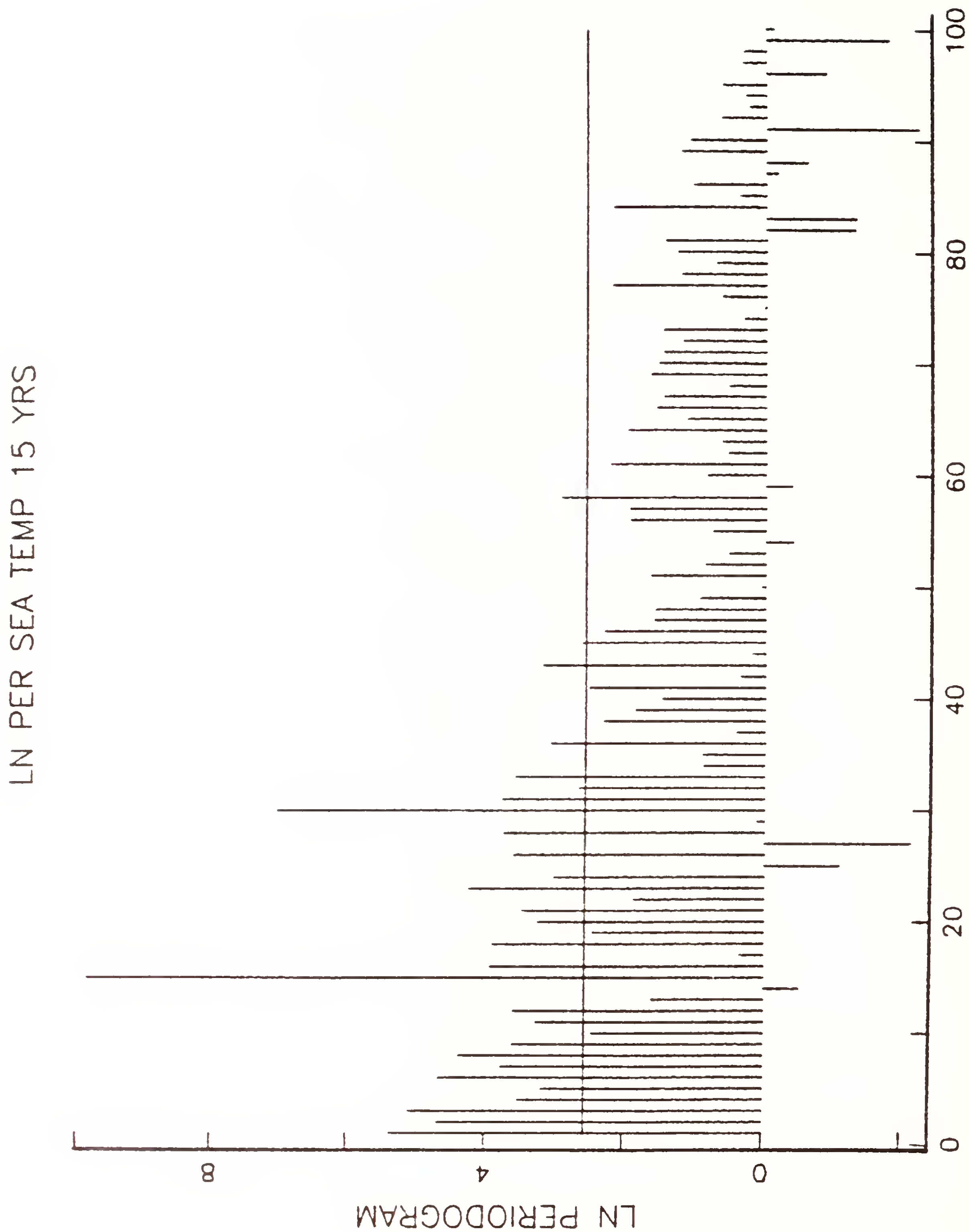


Figure 3

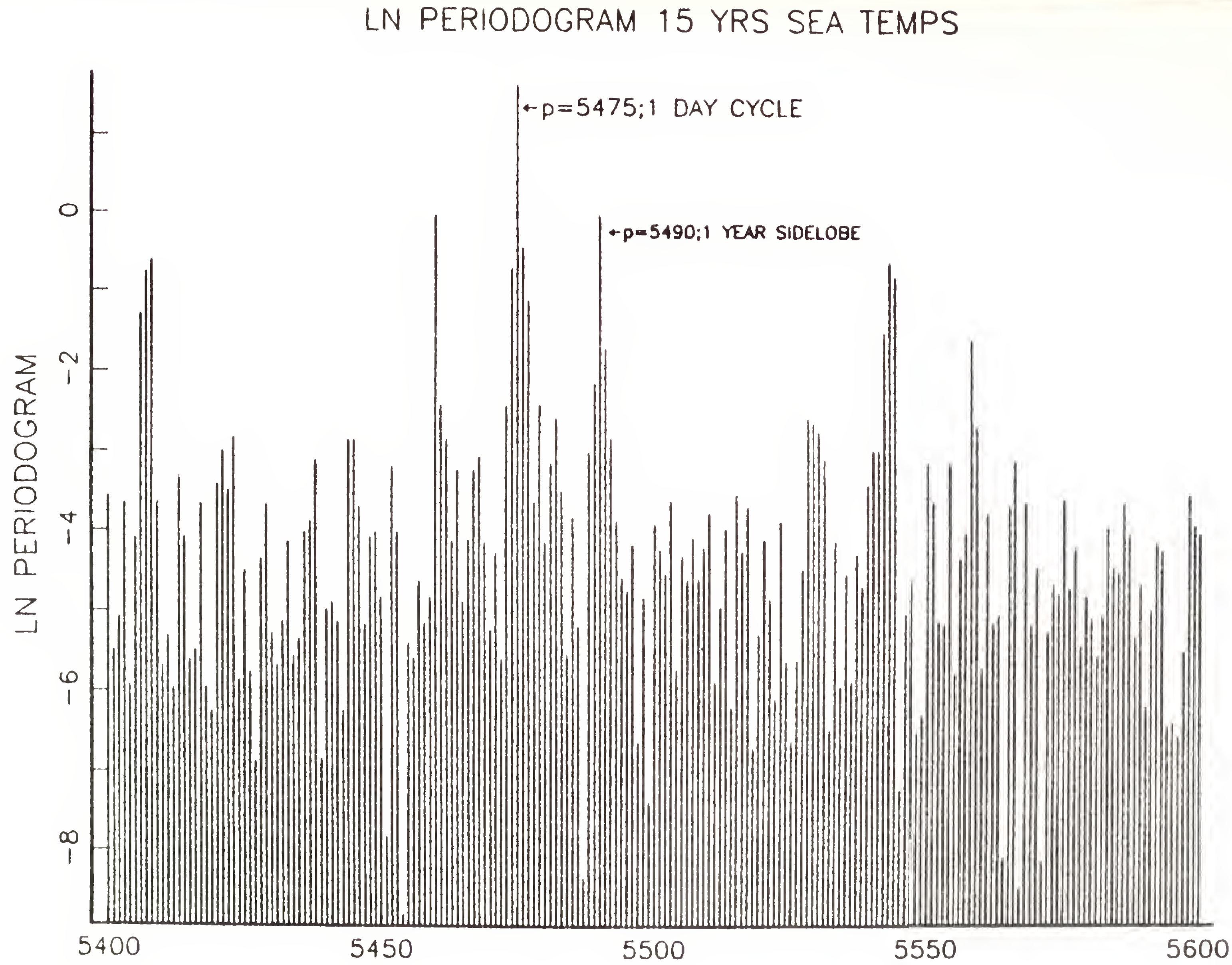

LN PERIODOGRAM 15 YRS SEA TEMPS
←p=5475;1 DAY CYCLE
←p=5490;1 YEAR SIDELOBE
LN PERIODOGRAM
0
-2
-4
-6
-8
5400
5450
5500
5550
5600

Figure 4

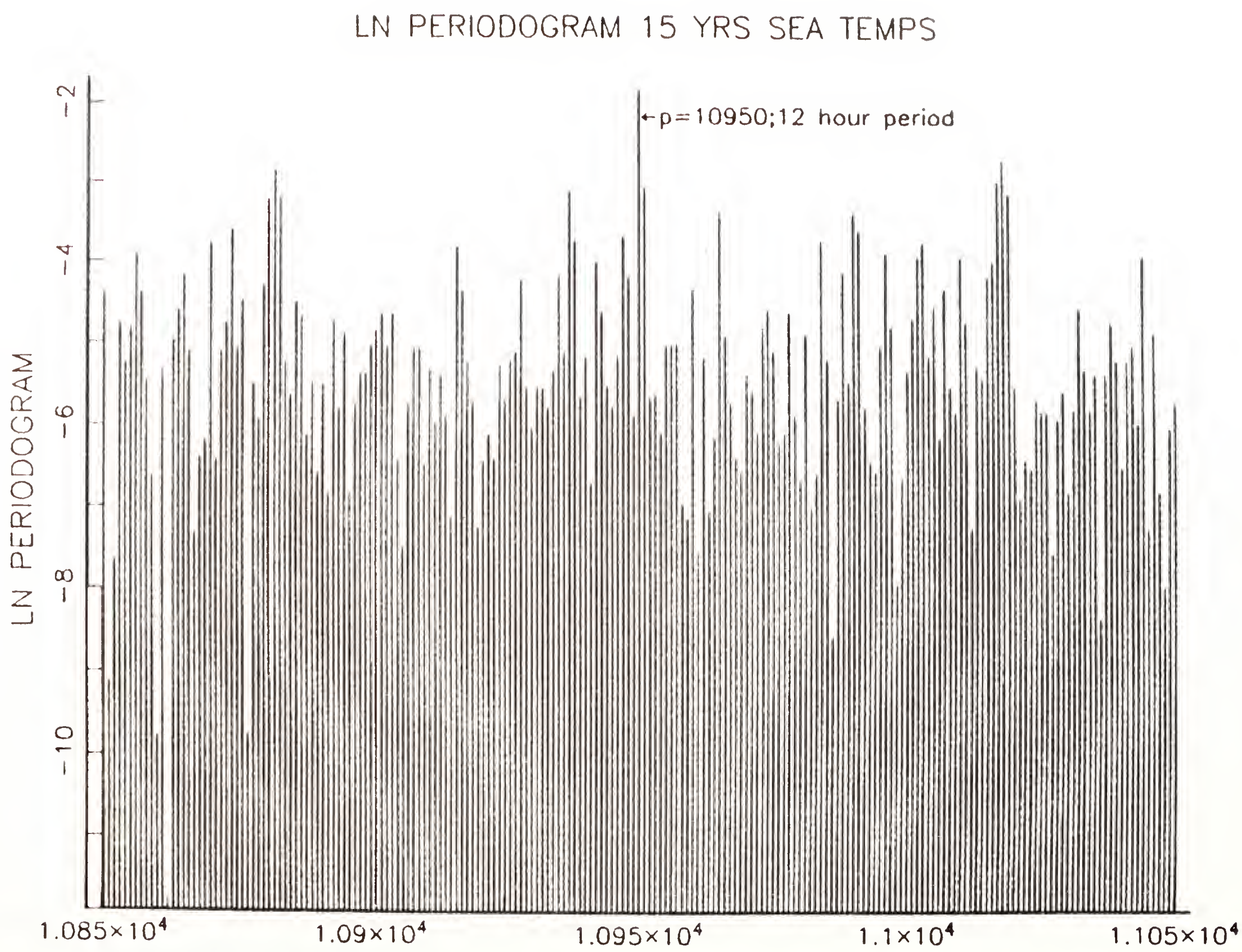

LN PERIODOGRAM 15 YRS SEA TEMPS
←p=10950;12 hour period
LN PERIODOGRAM
-2
-4
-6
-8
-10
1.085×10^4
1.09×10^4
1.095×10^4
1.1×10^4
1.105×10^4

Figure 5

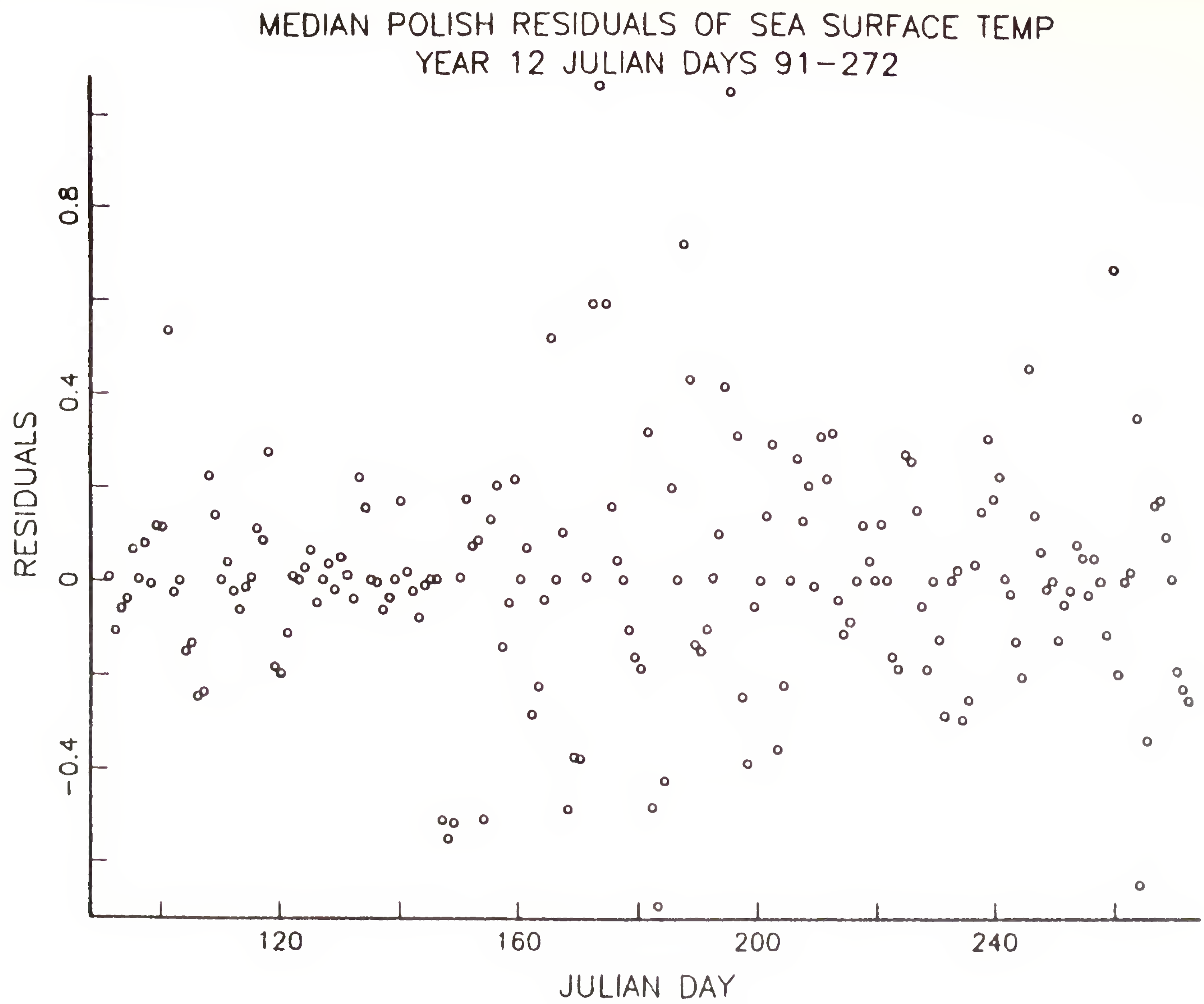

MEDIAN POLISH RESIDUALS OF SEA SURFACE TEMP
YEAR 12 JULIAN DAYS 91-272
RESIDUALS
0.8
0.4
0
-0.4
120
160
200
240
JULIAN DAY

Figure 6

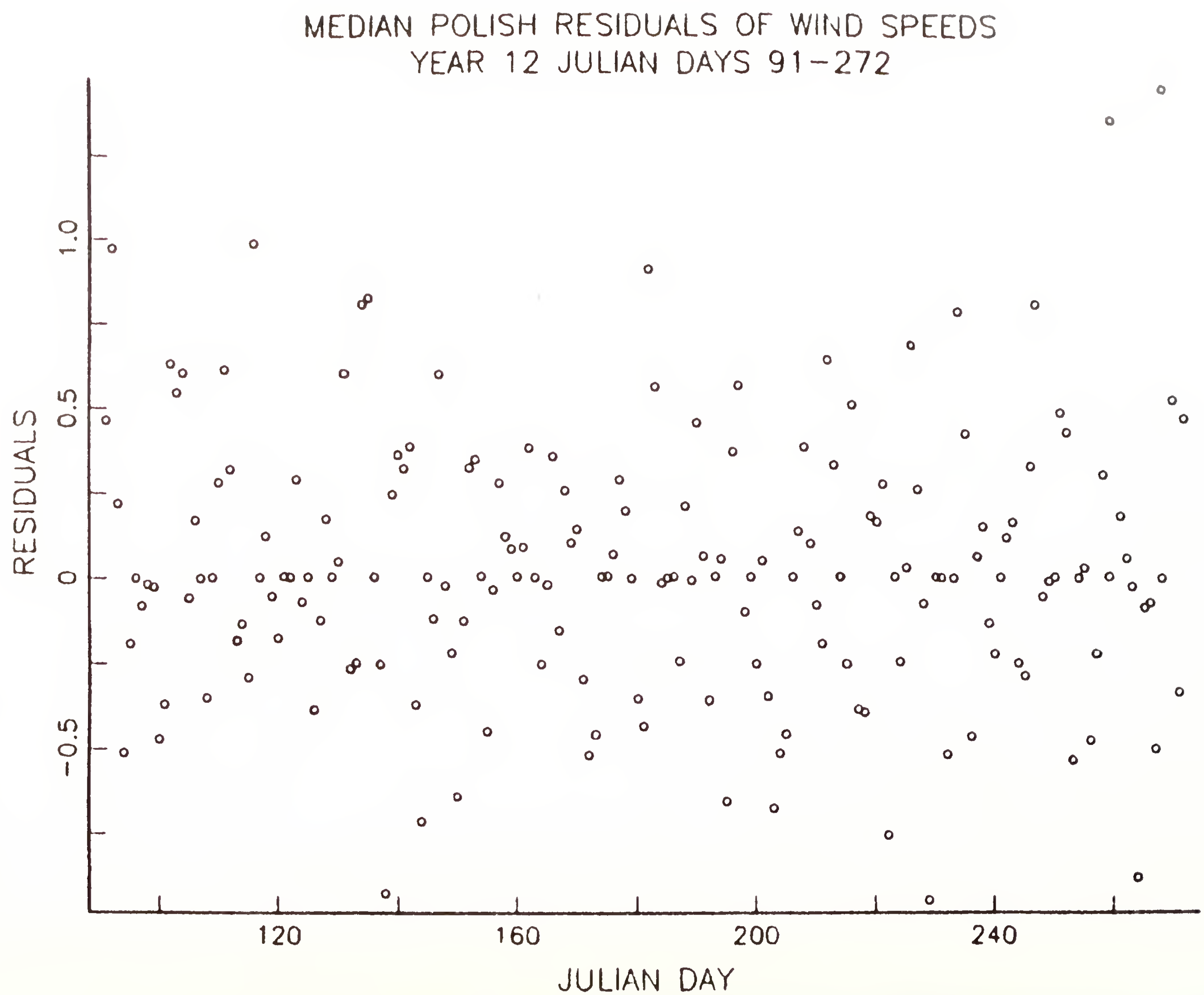

MEDIAN POLISH RESIDUALS OF WIND SPEEDS
YEAR 12 JULIAN DAYS 91-272
RESIDUALS
1.0
0.5
0
-0.5
120
160
200
240
JULIAN DAY

Figure 7

RESIDUAL WIND SPEED VS 1ST DIFFERENCE IN ÷((RES ST)+1) BY CATEGORY
YEAR 10

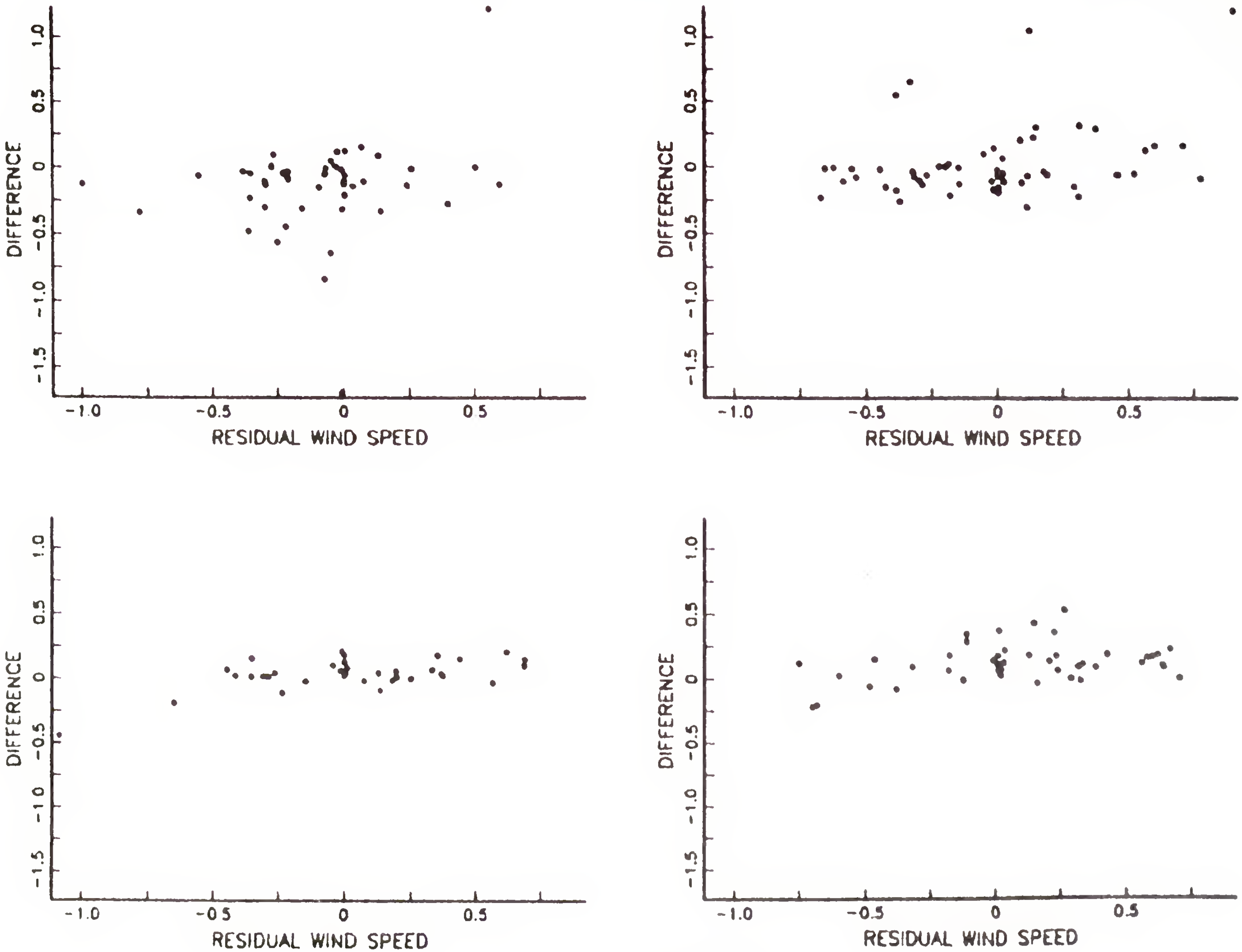
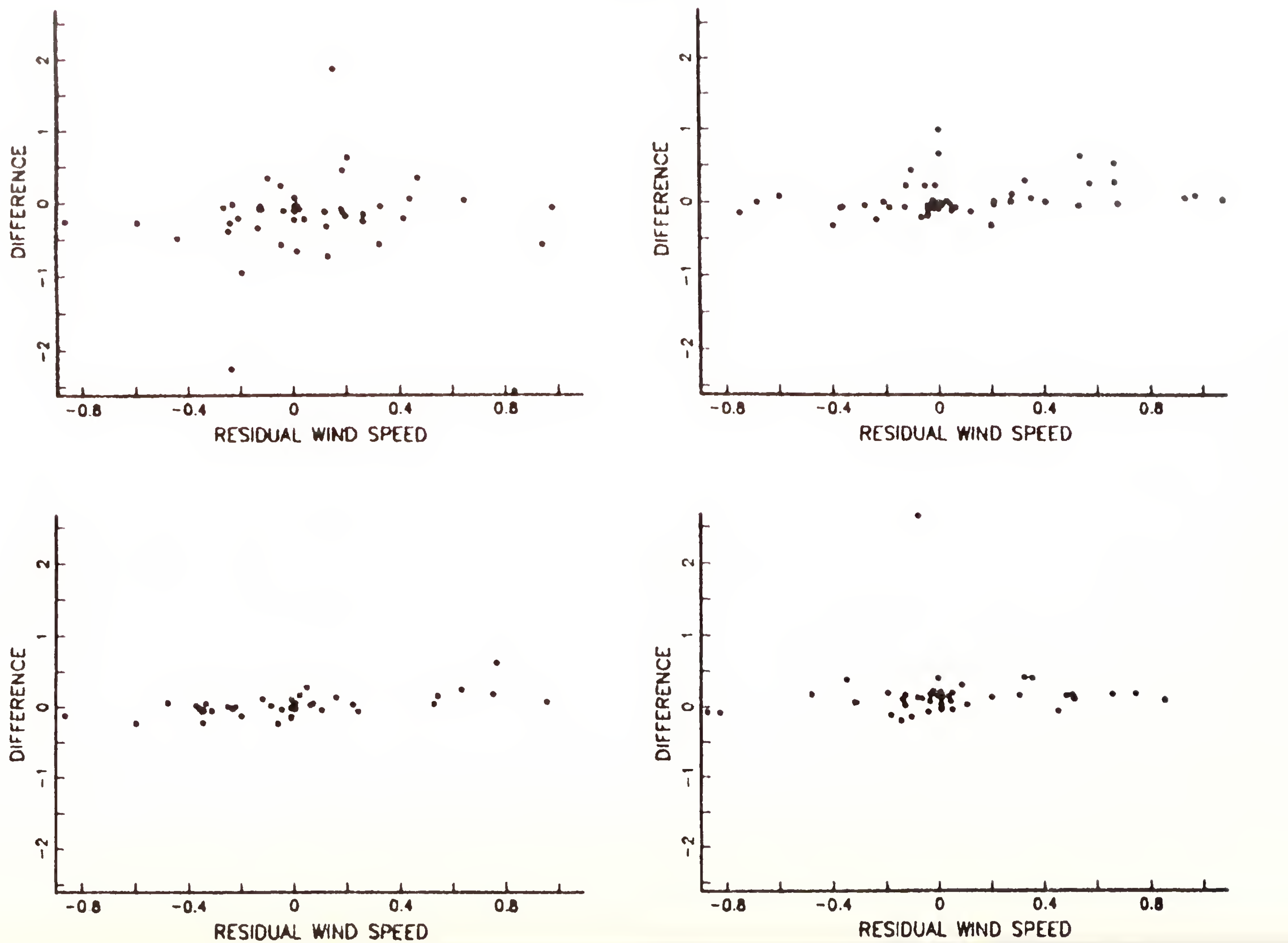


Figure 8

RESIDUAL WIND SPEED VS 1ST DIFFERENCE IN ÷((RES ST)+1) BY ST CATEGORY
YEAR 11



RESIDUAL WIND SPEED VS 1ST DIFFERENCE IN ÷((RES ST)+1) BY ST CATEGORY
YEAR12

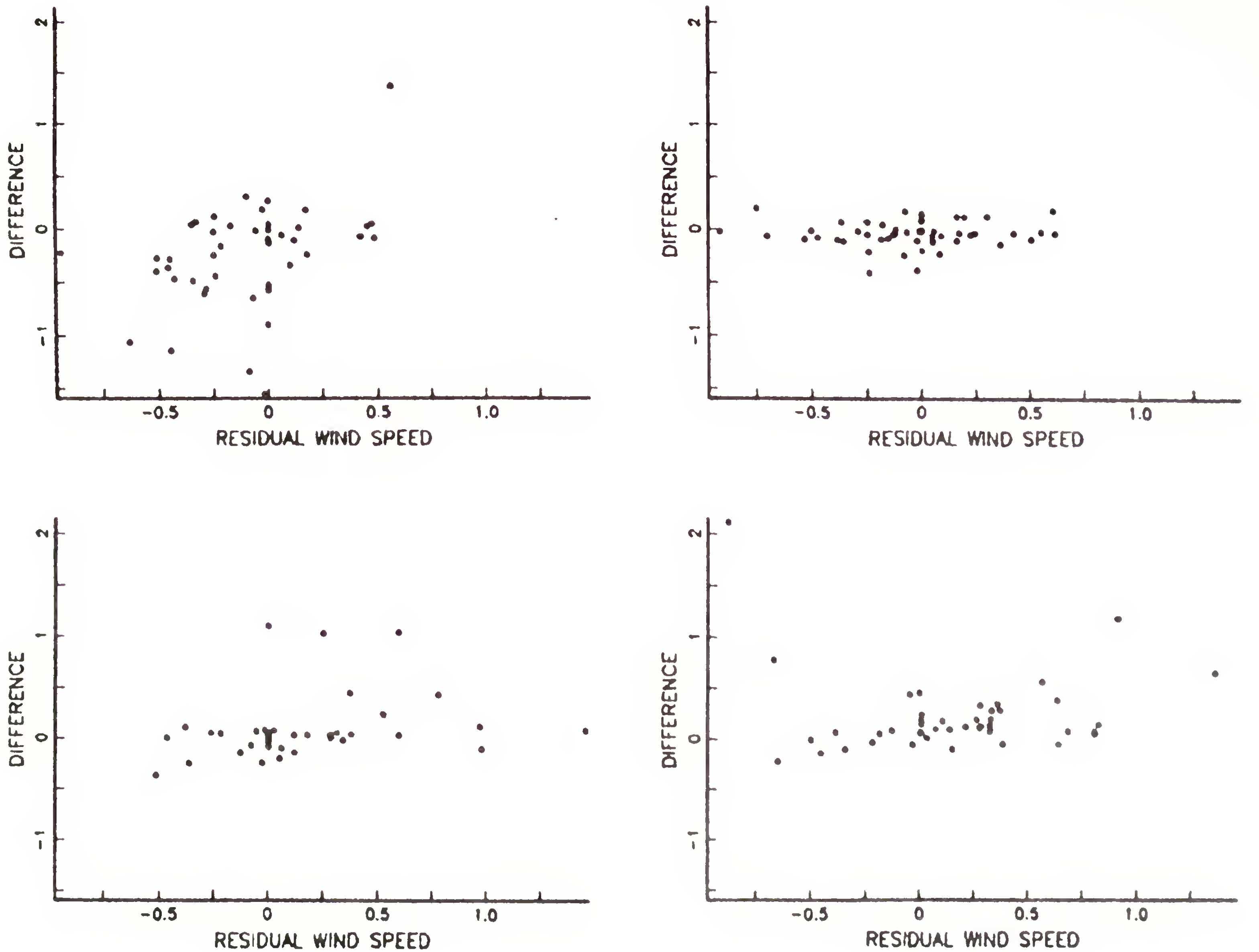
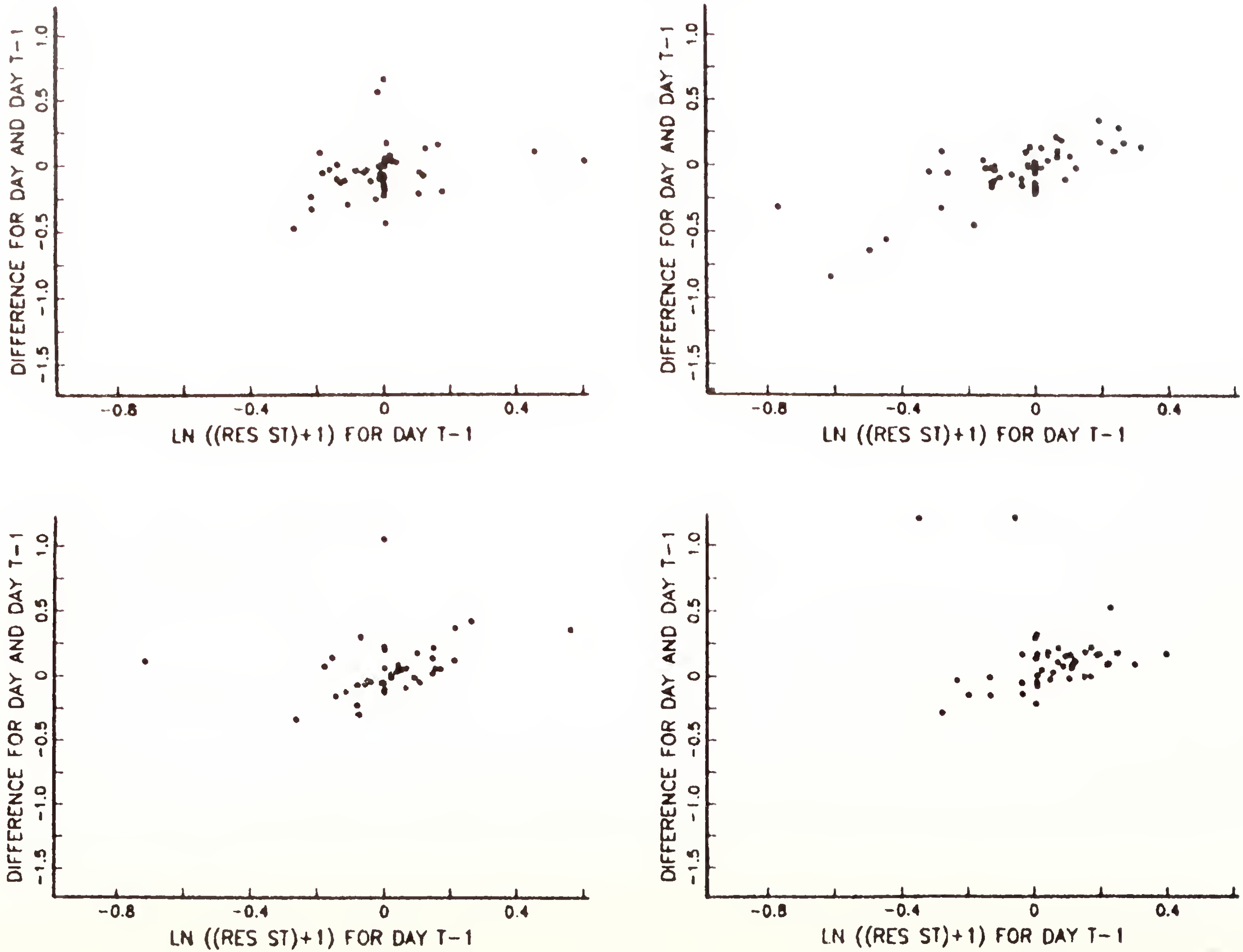


Figure 10

DIFFERENCE OF ÷((RES ST)+1) VS LN ((RES ST)+1) THE DAY BEFORE
BY CAT WIND SPEED;YEAR 10



DIFFERENCE OF ÷((RES ST)+1) VS LN ((RES ST)+1) THE DAY BEFORE
BY CAT WIND SPEED;YEAR 11

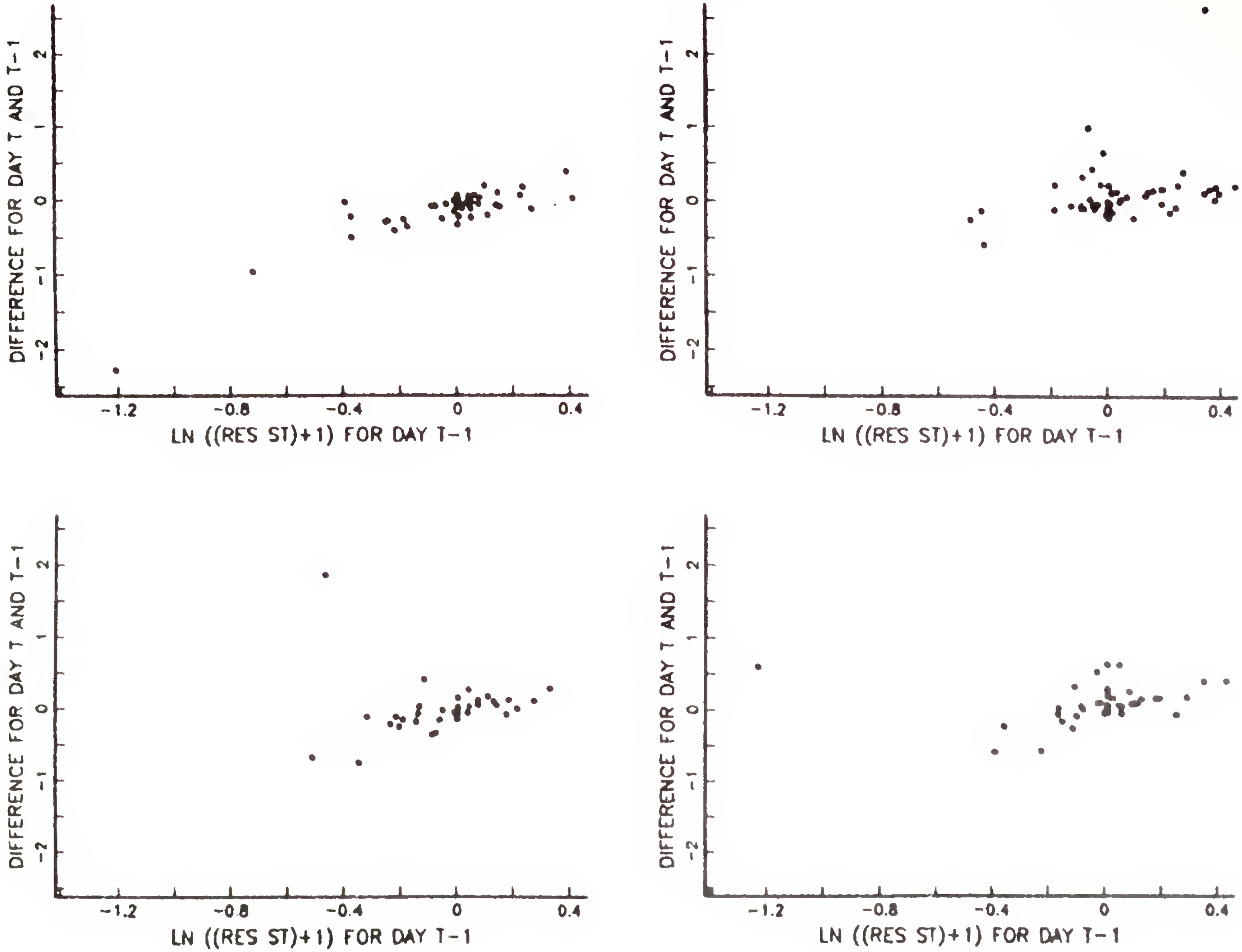
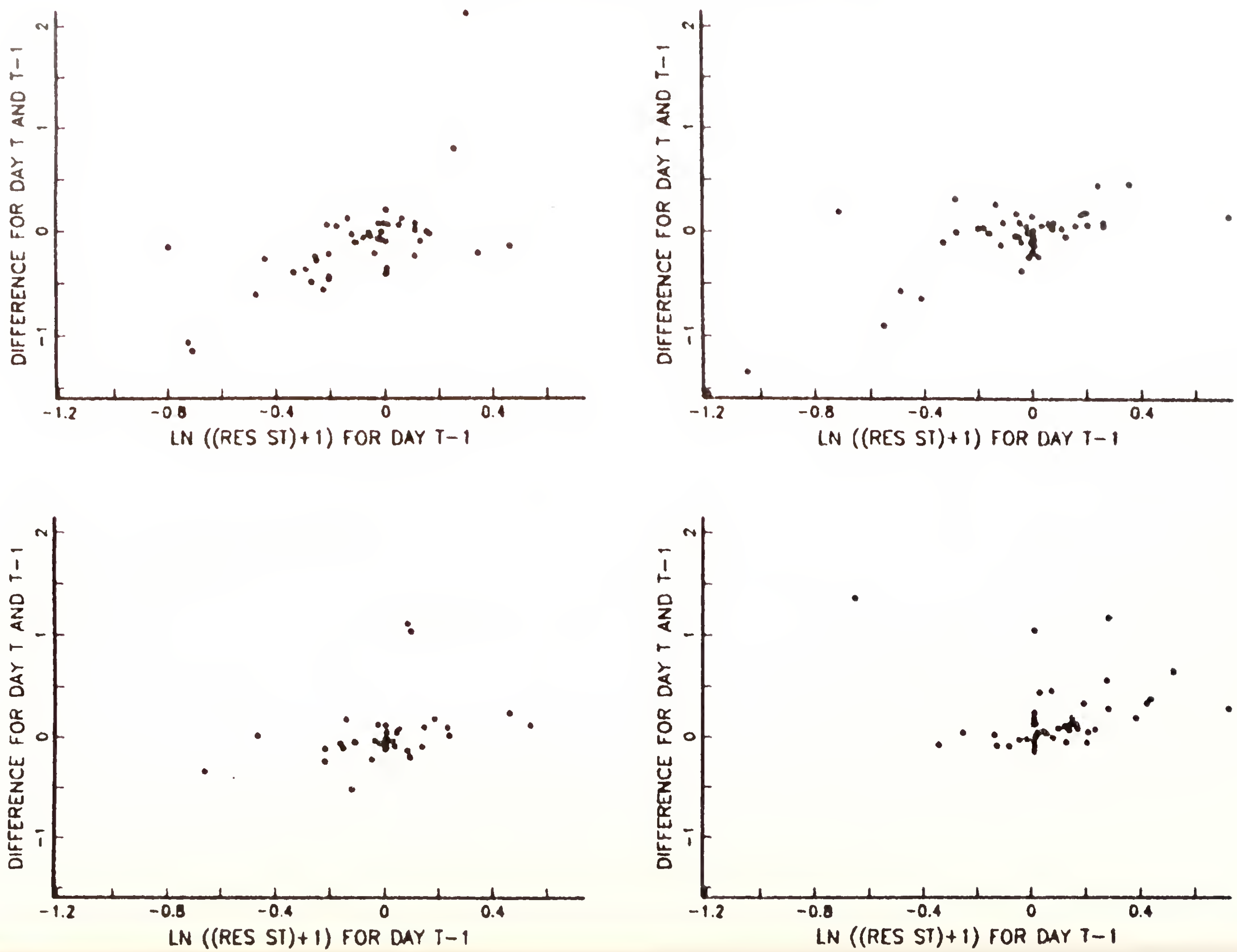


Figure 12

DIFFERENCE OF ÷((RES ST)+1) VS LN ((RES ST)+1) THE DAY BEFORE
BY CAT WIND SPEED;YEAR 12



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